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The feasibility of economic viability of hybrid PV-diesel energy system connect with the main grid in Somalia

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Abstract

Somalia has abundant resources in renewable energy; however, more than 90% of the electricity uses diesel, which is imported from outside the country and causes temperature rise and high electricity prices. This study examined the feasibility of several hybrid systems in Somalia's capital city, including solar Photovoltaic (PV), Battery Storage (BS), Diesel Generators (DG) and the main grid systems to minimize the levelized Cost of Energy (COE), Net Present Costs (NPC) and environmental impacts. Nine different system configurations were investigated, including stand-alone DG, stand-alone main grid system, Hybrid PV-DG with and without BS that connected to the main grid, Hybrid PV-DG with and without BS without connecting the main grid, Hybrid PV-Grid with and without BS system, and finally Hybrid DG-Grid system. Furthermore, the Hybrid Optimization Model for Electric Renewables (HOMER) is applied to optimize and analyze sensitivity. The result found that hybrid PV-DG-grid without battery storage system is the cheapest system in terms of NPC ($ 7.86M), COE (0.154 $/kWh), operating cost (339,775 $/yr), and renewable energy fraction of 24.6%.

Keywords: Renewable energy, economic, viability, hybrid system

1. Introduction

Though a considerable amount of energy is used every day, many decisions guarantee a steady energy supply. Fossil fuels, such as coal, oil, and natural gas, were the main energy sources responsible for rising temperatures. It is more difficult to find a solution to this problem, as there are already over 7 billion people on the planet, and that number is expected to add 1 billion every dozen years. Therefore, researchers and politicians have searched for renewable energy such as wind, PV, biomass, and tidal waves to replace conventional fossil fuels. Renewable energy is one of the main vital solutions to cut this issue because these energies are clean and environment-friendly, helping prevent global warming.

Various researchers in the field are carrying out many research projects and studies on renewable energy. In this instance, Laetitia Uwineza et al. [1] undertook feasibility studies of integrating the renewable energy system on Popova Island with the Monte Carlo model and HOMER. This paper is renewable energy system on Popova Island with the Monte Carlo model and HOMER. This paper is about exploring ways to increase the amount of renewable energy used on Popova Island. Applying the Monte Carlo method, an energy systems model, and then analyzing the financial outcomes is the strategy adopted. Granular results can be beneficial to stakeholders since they present a wide range of result scenarios. Another case study conducted by Tareq Salameh et al. illustrates the effective use of a hybrid renewable energy system in Neom City. Nine hybrid energy system (HES) cases were evaluated to supply a given demand. HOMER Pro is used to simulate and optimize the hybrid energy system under consideration. According to the economic, environmental, and social assessment, the optimum results were quite close for some circumstances. This case study shows that solar PV, battery energy storage, and digital data were optimal economic, environmental, and social analyses. The COE of electricity and

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hydrogen were \$0.4/kWh and \$21, respectively, for the best HES. This corresponds to saving around 118,074 gallons of diesel each year [2].

Mohammad Hossein Jahangir et al. selected ready and deferrable loads for use with hybrid renewable energy systems to help hospitals [3]. A comparison between the techno-economic, environmental and techno-environmental characteristics is addressed in this article. The case study is the aforementioned Tehran hospital in Iran. This building's load consumption is roughly 5342.46 kWh/day, provided by the city grid. The simulation incorporates an extended project module, incorporating lifetime changes. This instance has an energy cost of \$0.113/kWh and CO_2 emissions of 1555804 kg/year. In calculations, the usage of the grid-connected scenario yields cost savings of 44.2% and 50.2% multiple times and results in a Carbon dioxide (CO_2) emission reduction of 66%. Specifically, in the case of a grid-connected system, the amount of CO_2 is reduced by 15.3% for many years, while in the case of an off-grid system, it is cut by 5.8%. The Optimization and scaling of an SPV/Wind hybrid renewable energy system: A techno-economic and social approach performed by Faizan A [4]. Khan et al. can be found here. This research aims to create a hybrid renewable energy system used on farms in northern India. When considering the solar PV-wind-diesel generator battery storage, it was discovered that it is the most favorable combination for continuous power delivery. \$0.179 and \$31,439, respectively, equal the net present cost and cost of energy. Efforts to mimic the operation of biomass gasifiers in hybrid renewable energy micro grids were carried out by David Ribo-Perez simulating feeding an electric generator using syngas produced in a downdraft biomass gasification plant. Two case studies from Honduras and Zambia demonstrate the procedure's viability. Islanded biomass-photovoltaic hybrid renewable energy micro grids were also demonstrated to be feasible and profitable. Because micro grids have a lower COE than extending the electric grid to more towns, they are preferred [5].

S.M. Dawoud The city of Hurghada has supplied electricity by combining renewable resources such as solar and wind [6]. A reliable way to attain energy sustainability has been created through different hybrid renewable sources of household loads. A combination of wind turbines, DG, BS, and (PV) modules may be employed in residential installations. In the simulation, optimization, and modeling stages, HOMER software is used. Mohammad Hossein Jahangir performed an economic and environmental assessment of a solar-wind-biofuel hybrid renewable energy system that supplies a significant percentage of the rural settlement load. The system, which consists of PV panels, wind turbines, and biogas generators, provides rural electrification in Iran's Fars region. Because this off-grid system does not rely on fossil fuel power plants and does not produce CO_2, it inhibits the development of new fossil fuel power plants and the resulting CO_2 emissions. Sensitivity studies are used to find the ideal system configurations given the biomass feedstock, price, and inflation rate. There is a clear relationship between the inflation rate and the cost of power COE. Optimal systems have a COE between 0.128 and \$0.223 per kilowatt-hour to 22, resulting in increased biomass prices of roughly \$1. reducing the biogas generator's power generation by at least 86% cuts the cost of the generator by at least \$60/ton [7].

A 100% renewable energy micro grids on university campuses are supported by integrated PV/wind/biomass and hybrid energy storage systems created by Loiy Al-Ghussain et al. [8] in order to discover if the best size of PV/wind/biomass hybrid system has an NPC PV equal to or bigger than zero when furthermore incorporating energy storage. This study evaluates the capacity of the proposed system's different components. The Northern Cyprus Campus of the Middle East Technical University (METU) was used as a case study. In the proposed system, there will be a 1.79 MW PV, 2 MW wind turbine, and 0.92 MW biomass systems, which together will have a total capacity of 24.39 MWh and use 24.39 MWh of pumped hydro storage capacity along with batteries with an energy capacity of 148.64 kWh to obtain an overall FR of 99.59% and demand-supply fraction of 98.86%. Simulations revealed that a hybrid energy storage system integrated with PV/wind/biomass ensures near 100% autonomy. Sweta Singh spearheaded a decision-making strategy for rural electrification in India. Eight micro grid scenarios were evaluated, each assessed on several different criteria that included economic and environmental issues. To determine the best micro grid scenario, the Tomada de Decisao Interativa Multicriterio approach is first used. When the system that incorporates PV, DG, BS, fuel cell, wind turbine, and converter is studied, it is the most practical system in the considered location [9]. Sunay Turkdogan carried and optimized an entirely renewable hybrid energy system for domestic electrical loads and a hydrogen fuel cell electric car [10]. The purpose of this project is to investigate alternative energy sources and to create a hybrid energy system capable of meeting all of a single-family house's energy requirements, including utilities and transportation. HOMER software was used to create and optimize the system.

Vendoti Suresh et al. modeled and optimized an off-grid hybrid renewable energy system for rural electrification. The primary goal of this study is to minimize the Total System NPC, the COE, unmet load, and CO_2 emissions through the use of Genetic Algorithms and HOMER Pro Software. The findings of the two approaches are compared to four hybrid renewable energy system combinations [11]. First, Jean De Dieu Niyonteze conducted a study on the critical technology development needs and application of renewable energy hybrid technologies in off-grid areas for the Rwandan power sector [12]. This study covers some of Rwanda's emerging technology development demands in the power sector. Second, four different 100% renewable energy hybrid systems were created and simulated to support rural and distant areas with an average load requirement of 158.1 kWh/day and a peak load of 18 kW. Third, HOMER software was used to simulate and optimize hybrid systems.

Several hybrid power systems were examined in this study, including PV, BS, DG, and the city's power grid systems. The researchers examined the feasibility of using these in Somalia's capital city (MOGADISHU) and their net present cost, current net costs, and environmental impacts. Nine different configuration systems were examined, includıng stand-alone DG, stand-alone main grid system, Hybrid PV-DG with and without BS with grid connection, Hybrid PV-DG with and without BS without grid connection, Hybrid PV-Grid with and without BS system, and finally Hybrid DG-Grid system. The HOMER is used to optimize and examine the responsiveness of renewable power systems.

2. Description of the Case Study

Shallow wells and boreholes are very popular for use in Somalia. However, the government is not controlling the water, so all of the water wells are controlled by private companies. These companies are selling water to households, hotels, government buildings, and wherever water is needed.

Tawakal boreholes in Mogadishu city are used as the case study. This well is one of the most famous wells in Mogadishu, with more than 3,500 users, including houses, hospitals, and schools. Also, it Produces an average of 23998 cubic meters per month. Fig. 1 illustrates a representative sample of the company's daily load profile. The average daily energy use of the company is 6241.5 kWh. The company's demand load varies twice daily, once at 6 am and again at 6 pm. The company requires 259.3 kW of the baseload during the daytime since this is the only time the water pump is used. On the other hand, the maximum demand occurs at night time which reaches 261.3 kW, and it is time the company uses some lighting equipment.

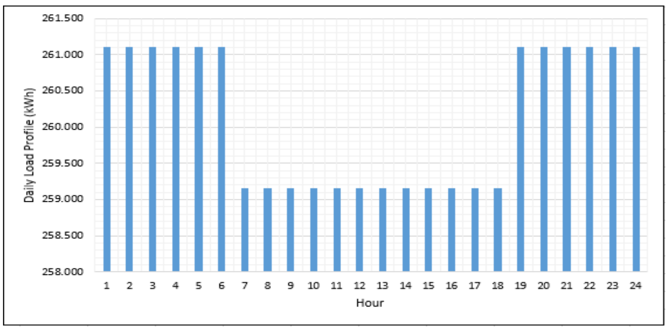

Fig. 1. The daily load profile of the company.

Fig. 2 illustrates this company's monthly load profile. February, March, and April have the highest electricity demand because they are summer months. The reason for higher energy demand in these months is that the well’s water decline, so the water pump needs much energy to carry it and people, animals, plants, and the ground need more water to use.

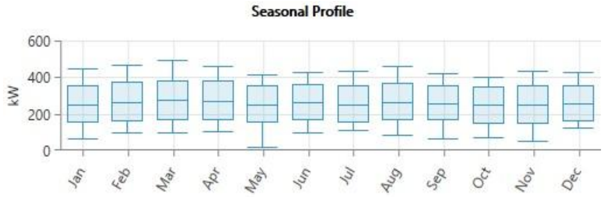

Fig. 2. The monthly load profile of the company.

3. Study of Renewable Energy Resources

Fig. 3 represents the monthly clearness index and solar radiation in Mogadishu. Somalia happens to the equator geographically, which means the average length of the day and night is equal for the whole year. As shown in Fig. 3, February has the highest clearness index of 0.647 and solar radiation of 6.63 kWh/m2/day, while July has the lowest clearness index of 0.519 and solar radiation points 5 kWh/m2/day [13].

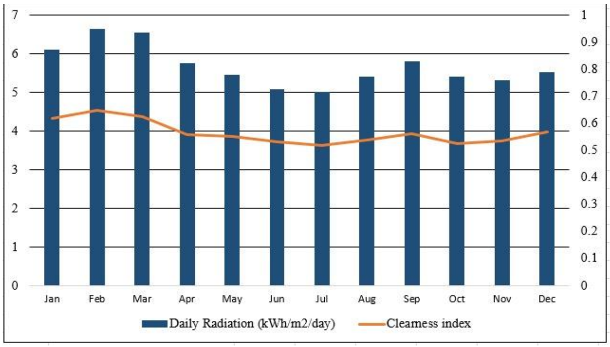

Fig. 3. The daily solar radiation and the clear index in Mogadishu.

As shown in Fig 4, since Somalia is located on the equator, the average monthly temperature has no big difference in the 12 months throughout the year. For instance, the highest temperature is 28.45 ℃ which occurs in March, while the lowest temperature is 26.04 ℃, and it occurs in August; therefore, the difference is 2.41 ℃ [13].

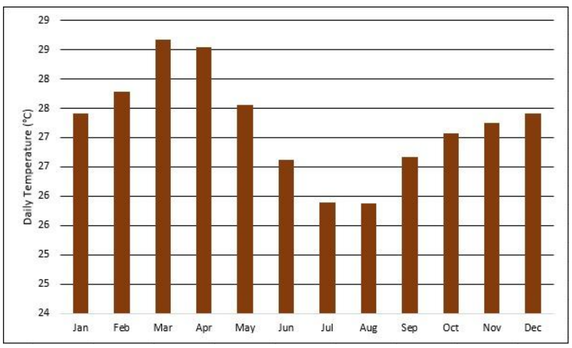

Fig. 4. The daily temperature in Mogadishu.

4. Grid Price

Since the collapse of Somalia's national government in 1991, the vibrant Somali private sector has been entirely responsible for electric power generation. Currently, more than seven electricity companies operate in the city – all owned by private individuals. Approximately 106 MW of installed capacity is currently available. While most power companies generate electricity using diesel generators, interest and investment in hybrid systems that utilize solar and wind energy resources are increasing.

In Mogadishu, there are three main power companies called BECO, Mogadishu, blue sky. This study will take BECO, which is the biggest electric supply company in Somalia, into consideration. BECO was founded in 2014 in Mogadishu - Somalia, by three of the few local electricity suppliers in the capital who understood the importance of joining forces to serve their clients better. These companies have decided to unite under a single, bigger & more resourceful entity called BECO, creating the largest electricity company in Somalia [14]–[16].

Beco electricity is generated from diesel-fueled generators and solar farms. Beco has installed 65MW, where 8MW is a solar farm that is the biggest renewable energy generation site in Somalia at large. Diesel generators and solar farms are combined within a Hybrid system with SCADA-controlled configuration. When it comes to the price of electricity in Somalia, it is not easy to navigate because the Somali government is not in control; thus, every organization must interact with each individual in their way. However, the three main companies in Mogadishu supply electricity; they charge 0.54 \$/kWh for residential and small business customers; those who use more electricity charge 0.25 \$/kWh for those who use less.

5. The Design and Configuration of Systems

This section presented each component's design specification with various operation conditions and the resulting output power equations. Solar, diesel generator, grid, battery, converter, and load demand are all components of the system presented in this research, as shown in Fig 5. Also, Table I presents the specifications of the chosen elements.

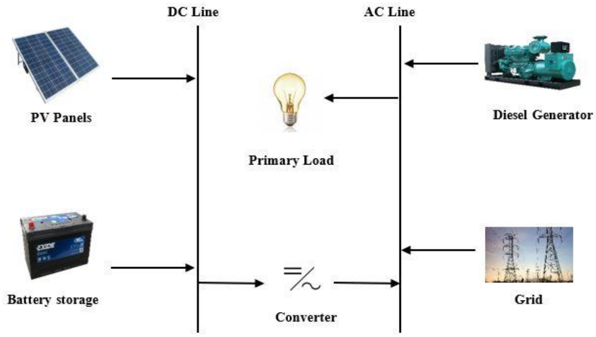

Fig. 5. The suggested hybrid energy system block diagram.

Table 1. The technical and economic definition for the proposed system's components.

Components			Cost			Life span
Name	Model	Size	Capital	Replacement	Operating cost	years
Diesel Generator	Autosize Genset (Homer Model)	0 to 350 kW (step of 50 kW)	$ 168.77 /kw	$ 168.77 /kw	0.01 $/yr	15,000 Hours
Photovoltaic	Solar cell : 4BB mono 156mm	0 to 350 kW (step of 50 kW)	$ 400 /kW	$ 400 /kW	$ 0.01 $/yr	25
Battery	DC12-150(12V150Ah)	150 Ah	$ 208.35 kWh	$ 208.35 kWh	$ 0 $/yr	5
Convertor	EP1800 Series	100 kW	$ 263 kW	$ 263 kW	0.01 $/yr	8

5.1. PV sizing

Solar cell: 5BB poly 156mm of polycrystalline solar panel with a rated power output of 200 Wp was chosen as the PV module for this study [17].

Table 1 details the technical characteristics of the photovoltaic module. In terms of solar radiation and temperature impact, the output power of the photovoltaic system is calculated using expression (1) [3].

$$P_{PV} = f_{PV} \cdot Y_{PV} \cdot \frac{I_T}{I_S} \tag{1}$$

Where;
Y_{PV} : The rated capacity of the PV array (kW)
I_T : The global solar radiation incident on the surface of the PV array (kW h/m2).
I_S : 1000 W/m2;
f_{PV}: PV derating factor (accounts for the negative effects of dust, wire losses, elevated temperature, or anything else on the performance of PV panel. A derating factor of 80% was employed in this study).

5.2 Battery size

Solar Gel Battery DC12-150(12V150Ah) type battery is selected in this study. In this research, the battery will be used solely to store surplus photovoltaic energy, as the company's peak load is 55555 kW and the size of the photovoltaic array is 666666 kW. As a result, any surplus from photovoltaic energy would be used to charge the battery storage [17].

5.3 Diesel generator

When PV modules are insufficient, the load demand, in any case, DGs generally act as a backup system. DG is applied in off-grid energy simulations in this work. Diesel engines are assumed to have a lifespan of 15,000 hours. The following equation can be used to determine the number of gallons of diesel fuel consumed by DG each hour:

$$F_D(t) = A \cdot P_R + B \cdot P(t) \tag{2}$$

$P(t)$ and P_R mean the DG's output power at a specific time and rated power, respectively [4].

6. Economical Analysis

In the economy, it is critical to consider Net Present Cost (NPC), Cost of Energy, and operational cost (OC). Net Present Cost is the sum of the present value of the revenues a system will receive during its lifetime, less the present value of the costs it incurs over its lifetime. Capital costs, operating costs, and replacement costs are all included in the current costs. Therefore, the proposed system makes only salvage income during the whole lifetime of the device. Before finding out the energy price, one should first set the annual cost (AnnC) in the following equation [10], [18]:

$$\text{AnnC} = \text{CRF} * \text{NPC} \tag{3}$$

where CRF stands for capital recovery factor, and it is figured by Eq.4.

$$CRF(i, n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{4}$$

where i is annual real discount rate and n is number of years.

Real discount rate (i) is found by Eq. 5

$$i = \frac{i' - f}{1 + f} \tag{5}$$

where i is nominal discount rate which is the rate we can borrow money and f is inflation rate. After finding AnnC and served energy (Eserved), the cost of energy per kWh produced by the hybrid system can be found using Eq. 6.

$$\mathrm{COE} = \left(\frac{\mathrm{AnnC/yr)}}{\mathrm{Eser\ \ eed}\left(\frac{\mathrm{kWh}}{\mathrm{yr}}\right)} \right) \tag{6}$$

Besides the cost of energy and net present cost, operating cost is another crucial parameter for the energy systems and defined as the annualized value of all costs and revenues with the exception of annualized capital costs which is found by-product of initial capital cost and CRF. For the other equations used in HOMER, it is recommended to check HOMER Instruction guide.

Table 2. Analysis of technical and economic information indicated a possible outcome.

Architecture				Cost			System
Solar (kW)	Diesel (kW)	Battery (unit)	Grid energy purchased (kWh)	NPC ($)	COE ($/kWh)	Operating Cost ($/yr)	Ren Frac (%)
350	250	--	116,551	7.86M	0.154	339,755	24.6
350	250	54	116,283	7.91M	0.155	341,550	24.6
350	300	26	--	8.51M	0.167	368,953	21.8
350	350	--	--	8.92M	0.175	387,126	21
--	250	--	99,698	9.67M	0.19	430,048	0
350	--	--	1,720,006	9.97M	0.195	435,933	24.6
350	--	54	1,720,370	10.0M	0.196	437,775	24.6
--	350	--	--	10.2M	0.20	453,410	0
--	--	--	2,278,161	12.8M	0.25	569,540	0

7. Results and Discussion

The simulation was carried out with a project lifetime of 25 years. The simulation was performed by comparing the various optimal configurations such as stand-alone DG system, stand-alone grid, hybrid solar-DG-Gr with and without a connected battery system, hybrid solar-DG with and without a Battery system, hybrid DG connect the grid system, hybrid solar with grid connect with and without battery system. As a result, the PV and DG capacity are varied for 0, 50, 100, 150, 200, 250, 300, and 350 kW.

According to the NPC, COE, operating cost, and Ren Frac, hybrid PV-DG-Gr without battery storage system is the cheapest system (winning system), as shown in Table 2. This winning system's PV and DG capacity is 350 kW and 250 kW, while the grid energy purchased is 116,551 kWh; also, this system has the lowest NPC, COE, operating cost of $ 7.86M, 0.154 $/kWh, and 339,755 $/yr. Additionally, when coupled with the battery, this system is the second-best configuration system according to all cost scenarios; the capacity of the DG and PV remains constant, but the energy purchased from the grid is reduced by 268 kWh, While the NPC, COE, and operating costs all increased slightly, the battery count is 54 units.

Table 2 shows that the third-best system is an off-grid hybrid PV-DG with a battery system. In this system, the capacity of PV remains 350 kW; however, the DG capacity reached 300 kW while 28 units reduced the battery unit and the renewable fraction declined by 2.8 %; this is due to the increasing size of the generator. Also, comparing the winning system, this system has a disadvantage: the NPC reached

$ 8.51M, COE is 0.167 $/kWh, and the operating cost is 368,953 $/yr. However, this system is the next option; the difference is not so great that the cost has slightly increased.

The 250 kW DG connected grid system, the hybrid system is the greatest option among standalone grid and hybrid PV-Gr systems with and without storage elements. However, this system also has renewable fraction of 0%, which is not environmentally friendly. The NPC, COE, and operating costs of this system are $9.67M, 0.19 $/kWh, and 430,048 $/yr. Additionally, this system purchases the least amount of grid electricity at 99,698 kWh.

A hybrid photovoltaic (350)-grid system without storage is the second alternative after the DG-grid system. This system has fewer downsides than the DG-grid system, such as a higher NPC, COE, and operating cost of 0.3 million, 0.005 cents per kWh, and 5,885 cents per year. Additionally, the energy purchased is higher, at 1,620308 kWh, when compared to the DG-grid system. In terms of advantages, this system outperforms the DG-grid system by a 24.6% renewable fraction. The next alternative is a hybrid PV-grid with a battery system. The difference is not that great, as illustrated in Table II.

Finally, depending on economics, the two worst-case scenarios are standalone DG and standalone grid systems. On the other hand, a standalone DG system offers significant benefits in NPC, COE, and operational expenses. For example, the grid system's NPC cost is 12.8 million dollars, while the standalone DG system's cost is 10.2 million dollars. Additionally, the grid system's operating cost is 569,540 dollars per year, while the standalone DG system's operating cost is 453,410 dollars per year. Finally, the difference in COE energy is not significant; the grid-connected system is only 0.05 $/kWh more expensive.

Table 3. The environmental consequences of the proposed hybrid winning system.

Emission	
Quantity	Value (kg/yr)
Carbon Dioxide	1,374,208
Carbon Monoxide	8,118
Unburned Hydrocarbons	358
Particulate Matter	48.7
Sulfur Dioxide	3,504
Nitrogen Oxide	7,786

The winning hybrid systems' greenhouse gas (GHG) emissions are shown in Table III. Carbon Dioxide, Carbon Monoxide, Unburned Hydrocarbons, Particulate Matter, Sulfur Dioxide, and Nitrogen Oxide emissions are listed in kilograms. This technology achieves the greatest net reduction among all other systems in GHG emissions. This is because renewable energy accounts for 24.6 percent of total energy.

8. Conclusion

This study evaluated the viability of different hybrid systems in Somalia's capital city, including PV, BS, DG, and main grid systems, with the goal of minimizing the Levelized cost of energy, net present costs, and environmental implications. Nine distinct system configurations were investigated: stand-alone DG, stand-alone main grid system, hybrid PV-DG with and without BS connected to the main grid, hybrid PV-DG with and without BS disconnected from the main grid, hybrid PV-Grid with and without BS disconnected from the main grid, hybrid PV-Grid with and without BS disconnected from the main grid, hybrid PV-Grid with and without BS disconnected from the main grid, and finally hybrid DG-Grid system. To optimize and analyze sensitivity, the hybrid optimization model for electric renewables (HOMER) is used. The outcomes indicate that a hybrid PV-DG-Gr system without battery storage is the least expensive system in terms of NPC ($ 7.86M), COE (0.154 $/kWh), operating cost (339,775 $/yr), and renewable energy proportion (24.6%).

Author Contributions

Conceptualization, Y.K.E. (Yonis Khalif Elmi), M.J. (Moein Jazayeri) and D.S. (Diaa Salman); methodology, Y.K.E., M.J. and D.S.; software, Y.K.E., M.J. and D.S.; validation, Y.K.E., M.J. and D.S.; formal analysis, Y.K.E., M.J. and D.S.; investigation, Y.K.E., M.J. and D.S.; resources, Y.K.E., M.J. and D.S.; data curation, Y.K.E.; writing-original draft preparation, Y.K.E. and D.S.; writing—review and editing, D.S.; visualization, Y.K.E., M.J. and D.S.; supervision, M.J.; project administration, Y.K.E.; funding acquisition, Y.K.E. and D.S. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

There are no conflicts of interest.

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